Predicting Stored Grain Insect Population Densities Using an Electronic Probe Trap

P. W. FLINN,[1] G. P. OPIT,[2] AND J. E. THRONE

USDA–ARS, Grain Marketing and Production Research Center, Manhattan, KS 66502

J. Econ. Entomol. 102(4): 1696–1704 (2009)

ABSTRACT Manual sampling of insects in stored grain is a laborious and time-consuming process. Automation of grain sampling should help to increase the adoption of stored grain integrated pest management. A new commercial electronic grain probe trap (OPI Insector) has recently been marketed. We field tested OPI Insector electronic grain probes in two bins, each containing 32.6 tonnes of wheat, *Triticum aestivum* L., over a 2-yr period. We developed new statistical models to convert Insector catch into insects per kilogram. We compared grain sample estimates of insect density (insects per kilogram of wheat) taken near each Insector to the model-predicted insect density by using Insector counts. An existing expert system, Stored Grain Advisor Pro, was modified to automatically read the Insector database and use the appropriate model to estimate *Cryptolestes ferrugineus* (Stephens), *Rhyzopertha dominica* (F.), and *Tribolium castaneum* (Herbst) density from trap catch counts. Management decisions using Insector trap-catch estimates for insect density were similar to those made using grain sample estimates of insect density for most sampling dates. However, because of the similarity in size of *R. dominica* and *T. castaneum*, the software was unable to differentiate counts between these two species. In the central and southern portions of the United States, where both species frequently occur, it may be necessary to determine the proportion of each species present in the grain by manual inspection of trap catch. The combination of SGA Pro with the OPI Insector system should prove to be a useful tool for automatic monitoring of insect pests in stored grain.

KEY WORDS *Rhyzopertha dominica*, *Cryptolestes ferrugineus*, *Tribolium castaneum*, sampling, stored grain

Pitfall probe traps have been used to estimate insect populations in stored grain for many years (Loschiavo and Atkinson 1967, Loschiavo and Smith 1986, Lippert and Hagstrum 1987, Vela-Coffier et al. 1997, Wakefield and Cogan 1999, Toews et al. 2005). These traps are composed of cylindrical tubes with small holes through which insects drop into a collecting tip in the bottom of the trap. The trap is normally inserted into the grain until the top is just below the grain surface, and the trap is left in place for 3–7 d. The trap is then pulled from the grain, and the insects in the tip are identified and counted. One of the problems with these traps is that it is necessary to enter the grain bin to insert and remove the traps from the grain. Many versions of the trap have been designed (Burkholder 1984, White and Loschiavo 1986, Madrid et al. 1990). Shuman et al. (1996) developed an electronic version of the trap that automatically counts insects as they fall into the tip. One of the advantages with an electronic trap is that it would continuously monitor insects caught by the trap over time; it would not be necessary to retrieve the trap from the grain every 3–7 d.

Pitfall probe traps are very good at detecting insects in stored grain and often can detect insects as much as 37 d earlier in grain compared with samples taken with a grain trier (grain sampling spear or probe) (Hagstrum et al. 1998). However, one of the problems with pitfall probe traps is that insect catch is strongly influenced by both grain temperature and insect species (Fargo et al. 1989); thus, it is difficult for untrained grain managers to use pitfall probe trap counts directly to make management decisions. A good alternative for grain managers is to convert trap catch into insect density (insects per kilogram of grain). Several researchers have developed statistical models to do this based on insect species caught per day and grain temperature (Hagstrum et al. 1998, Toews et al. 2005). However, these models are based on the WBII pitfall probe trap (Trécé, Adair, OK), not the electronic probe trap that was tested in this study.

An electronic probe trap with infrared-beam sensors (EGPIC) was developed to alleviate the need to enter the bin (Shuman et al. 1996, 2005). EGPIC has

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture or Oklahoma State University.

[1] Corresponding author, e-mail: paul.flinn@ars.usda.gov.

[2] Current address: Department of Entomology and Plant Pathology, Oklahoma State University, Stillwater, OK 74078.

gone through many design iterations during the last 10 yr. The EGPIC design was licensed by OPI Systems, Inc. (Calgary, AB, Canada) and is commercially available as Insector. The trap is 51.3 cm in length and has a 4.5-cm-square cross-sectional body with 1,080 entry holes (Shuman et al. 2005). The holes are 1.6 by 2.8 mm and slanted upward to reduce debris from entering the trap. The Insector is controlled by a computer program running on a personal computer (StorMaxPro). The current design uses a dual infrared beam to improve estimation of the size of the insect. The ability of the Insector to detect the size of the insect falling into the trap allows it to roughly identify several species of stored grain insect pests. As noted, to predict insect density from probe trap catch, it is necessary to know the counts for each species that were caught by the trap, as well as the grain temperature. In addition, knowing the species that are in the grain improves integrated pest management decision-making, because internal-feeding insect species cause much more damage to the grain than external-feeding insects.

Stored Grain Advisor Pro (SGA Pro) is an expert system for managing insect pests in stored grain that makes insect control recommendations based on estimates of insect density in the grain by using vacuum probe or grain-trier samples (Flinn et al. 2007). SGA Pro is freely available to the public at the Grain Marketing and Production Research Center website (www.ars.usda.gov/npa/gmprc/bru/sga). To facilitate interpretation of insect trap catch data, we modified SGA Pro to use Insector data to convert electronic counts into estimates of insects per kilogram for *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Laemophloeidae), *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae), and *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae). We first attempted to use statistical models from Hagstrum et al. (1998) and Toews et al. (2005) to convert the electronic counts of insects per day into insects per kilogram of wheat, *Triticum aestivum* L. However, these models were based on studies that used a different trap design, the WBII trap. Because the Insector is quite different than the WBII trap (the WBII holes are larger, and the Insector has upward sloping holes), we hypothesized that new regression models might be required to accurately predict insect density from Insector trap catch.

The objectives of this study were to test existing statistical models that predicted insect density from Insector trap catch, and develop new models for Insector if necessary. A second objective was to integrate SGA Pro with the Insector electronic probe traps so that it could automatically access the StorMaxPro database and convert trap catch into insect density to make management recommendations.

Materials and Methods

Two steel bins were each filled with 32.6 tonnes (1,200 bushel) of newly harvested hard red winter wheat on 21 July 2005. Bin dimensions were 4.72 m in diameter by 3.35 m in height at the eaves, and each bin was filled to a depth of 2.44 m. The grain temperature and wheat moisture content at the time of storage were ≈33°C and 12%, respectively. Five Insector electronic pitfall probe traps (OPI Systems, Inc.) were inserted into the wheat in the bin center, and the four cardinal directions (north [N], south [S], east [E], and west [W]). The five probes in each bin were pushed into the grain with the top of the probe 0.3 m below the grain surface; in each of the cardinal directions, the probe was 0.5 m from the bin wall. Two types of collection tips can be used with the Insector: tips with holes in the bottom to allow insects to escape and solid tips without holes to prevent insects from escaping. Solid collection tips filled to a depth of 1 cm with ethylene glycol were used with the Insectors for 1 wk, after which the Insectors were pulled out of the grain. Ethylene glycol was used to preserve insects that fell into the solid tip. On the same day the Insectors were removed, four grain-trier samples were taken around each Insector by using a 1.2-m open-ended trier; each sample weighed 480 g and was taken from the top 0.9 m of wheat and a distance of 30 cm from each Insector. The solid tips were then replaced with tips that had holes in the bottom and the Insectors were reinserted into the wheat. After 7 d, the Insectors were removed from the grain and the tips with holes were replaced with solid tips. This cycle repeated itself until the end of the study.

Insects collected in the solid tips were identified and counted. Grain samples were sieved using a U.S. Standard #10 sieve (2-mm openings) to separate insects from the grain. Because grain samples taken in July and August showed very low densities of *R. dominica* in the grain, we added 400 *R. dominica* adults to each bin on 1 September 2005. On 2 August 2006, we added 400 *R. dominica* and 400 *T. castaneum* because of low densities of these species in the grain. The insects were from a field-collected strain in Kansas that was <2 mo old. This was done to ensure that the most common and damaging insect pests of stored wheat in Kansas (*C. ferrugineus*, *T. castaneum*, and *R. dominica*) were present in the grain. Grain temperatures were monitored using temperature sensor cables (OPI Systems, Inc.). One cable was inserted next to each Insector and recorded grain temperatures every 30 cm, from the bottom to the top of the grain mass. The wheat was fumigated using phosphine in June 2006 and then reused for sampling from July through November 2006.

Data Analysis. We tested regression equations from Hagstrum et al. (1998) and Toews et al. (2005) to estimate insect density from daily trap catch. Separate regression equations were used for *R. dominica* and *C. ferrugineus.* Because the published equations for *R. dominica* did not fit the data well, we developed new regression equations for *R. dominica* and *C. ferrugineus* by using data from 2006, and we used data from 2005 for *T. castaneum* because 2006 insect densities were too low to fit an accurate equation We used regression analysis (Systat Software, Inc. 2007) to predict insect density as a function of manual counts of Insector trap

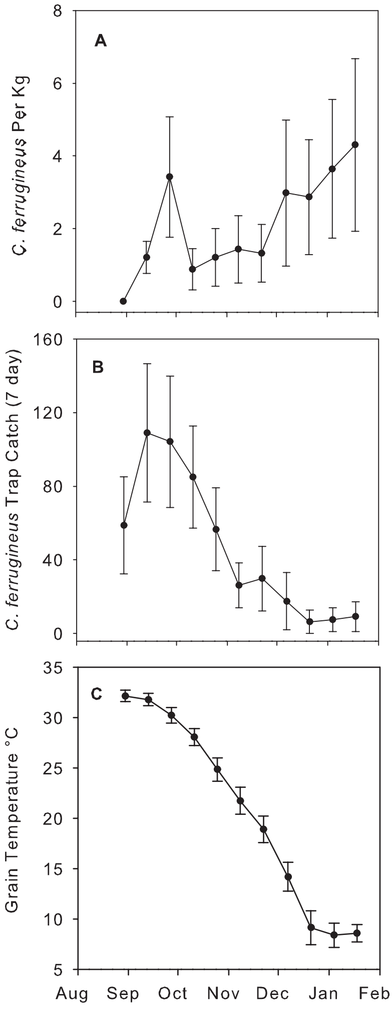

Fig. 1. 2005 Seasonal changes in average *C. ferrugineus* density (grain trier samples) (A), Insector tip counts (7-d catch) (B), and grain temperatures for bin 21, which contained 32.6 tonne of hard red winter wheat (C). Trends were similar for bin 22, so only data for bin 21 are shown.

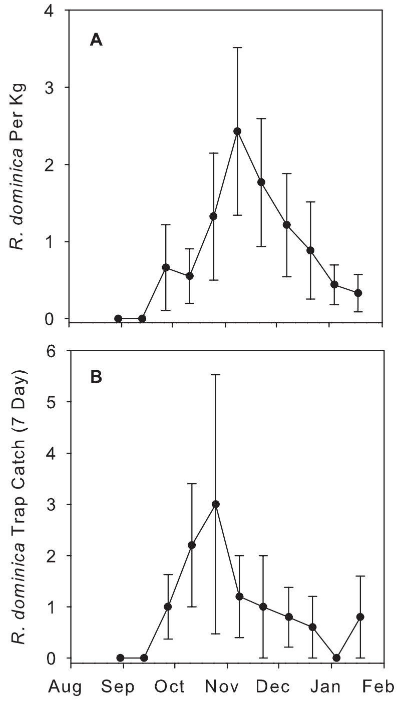

Fig. 2. 2005 Seasonal changes in average *R. dominica* density (A) and manual tip counts of *R. dominica* caught in the Insector trap (B). Grain temperature is the same as in Fig. 1.

catch per day and grain temperature. SGA Pro was programmed to automatically access the StorMaxPro database and convert trap catch into insect density using the regression equations. We compared SGA Pro's management recommendations by using both grain trier samples and electronic pitfall probe trap estimates.

Results

Population Trends. In 2005, *C. ferrugineus* density (indicated by grain trier samples) increased from August until we stopped sampling 18 January (Fig. 1A). The large standard errors were caused by the higher insect densities in warmer areas of the bin (center [C] and south [S] samples, and the lower insect densities in the cooler areas of the bin (north [N], east [E], and west [W]). Although the error bars are quite large, there is a general trend of increasing population density in the grain bin. In contrast, Insector trap catch of *C. ferrugineus* reached a peak on 5 September and decreased after this date (Fig. 1B). This was probably due to lower grain temperatures that decreased insect movement in the grain that led to decreased trap catch (Fig. 1C). Other researchers have reported similar temperature effects on trap catch (Fargo et al. 1989, Hagstrum et al. 1998, Toews et al. 2005). *R. dominica* density reached a peak on 8 November (Fig. 2A); this was similar to the peak in Insector trap catch (Fig. 2B). *T. castaneum* density reached its peak in November (Fig. 3A), and Insector trap catch peaked about one month earlier in October (Fig. 3B).

C. ferrugineus density (trier sample estimates) in 2006 reached a maximum on 26 September and remained high until the end of the study (Fig. 4A). Insector trap catch for *C. ferrugineus* followed the same general trend as the trier sample density (Fig. 4B). *R. dominica* density reached a peak on 24 October (Fig. 5A). Insector trap catch of *R. dominica* peaked 10 October, and then decreased until the last sampling date on 7 November (Fig. 5B). *T. castaneum* density reached a peak on 24 October, and Insector trap catch continued to increase until the end of the study (Fig. 6A and B).

For all three species in 2005 and 2006, insect density was much higher in the center of the bin and in the south sampling locations than in east, north, or west (Fig. 7). Temperatures remained warmer longer in the center (C) and south (S) portion of the bin, and this

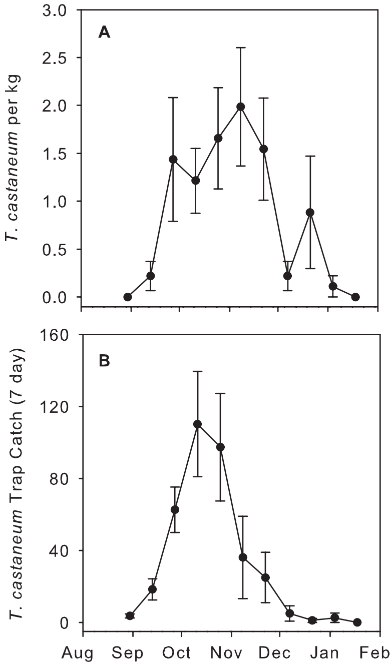

Fig. 3. 2005 Seasonal changes in average *T. castaneum* density (A) and manual tip counts of *T. castaneum* caught in the Insector trap (B). Grain temperature is the same as in Fig. 1.

allowed populations there to continue to increase during the fall and winter.

Insector Electronic and Manual Tip Counts. For species identification, we defined the size limits for a species to be classified as *C. ferrugineus* as >12 and <28 Insector relative size index (IRSI). The IRSI is based on the area of the shadow the insect casts on the infrared beam detectors as it falls into the collection tip (Shuman et al. 1996). This allowed us to differentiate psocids and *R. dominica* from *C. ferrugineus.* Most psocids are <12 IRSI, whereas most *R. dominica* are >27 IRSI. There was a fairly good correlation between electronic counts of *C. ferrugineus* and manual tip counts in 2005 ($R^2 = 0.57, P < 0.001, N = 95$) and 2006 ($R^2 = 0.66, P < 0.001, N = 84$). Insector electronic counts were ≈1.6 and 1.8 times higher than the actual tip counts in 2005 and 2006, respectively.

Because electronic counts of insect species are based on size, other species similar in size to *C. ferrugineus* may have been classified as such by mistake. For example, large psocids could be counted as a *C. ferrugineus.* Because the Insector estimates of the species size ranges were based on laboratory cultures (Shuman et al. 2005), we wanted to determine the actual size range for field-collected insects during our study. We dropped ≈300 dead adults each of *C. ferrugineus, R. Dominica,* and *T. castaneum* through an Insector under laboratory conditions and recorded the IRSI for each insect. There was not much overlap in IRSI distribution between *C. ferrugineus* and *R. dominica* (Fig. 8A and B). However, there was a large overlap in IRSI between *R. dominica* and *T. castaneum*

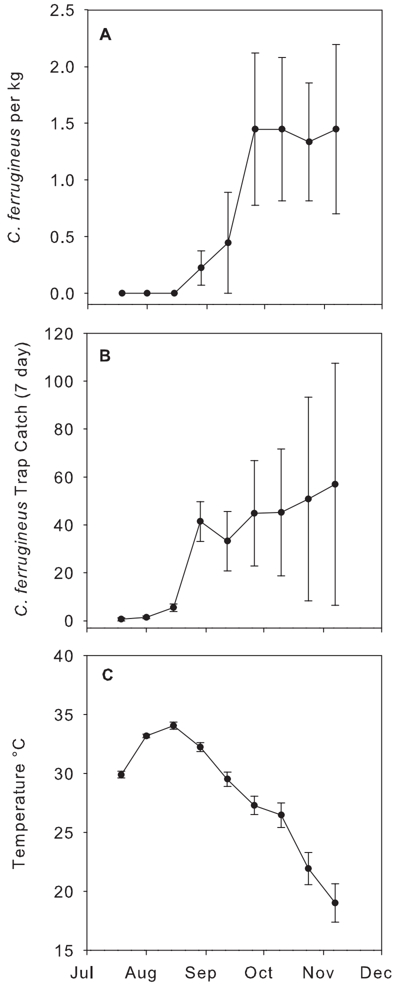

Fig. 4. 2006 Seasonal changes in average *C. ferrugineus* density (grain trier samples) (A), Insector tip counts (7-d catch) (B), and grain temperatures for bin 21, which contained 32.6 tonne of hard red winter wheat (C). Trends were similar for bin 22, so only bin 21 is shown.

(Fig. 8B and C). This means that when both species are present, Insector may be unable to differentiate between the two species. One solution to this problem may be to use the solid tips on the Insector when either species is suspected, and then the contents of the tip can be visually inspected to determine the proportion of each species at that sample location. Because of the overlap, we created a new size class for both *R. dominica* and *T. castaneum* and defined this as IRSI >27 and <60.

Because there were low densities of *R. dominica* in 2005, we decided to only look at the correlation between electronic and manual tip counts for *C. ferrugineus* and *T. castaneum,* and not *R. dominica.* Thus, most of the insects in the IRSI 28–59 size range would be correctly counted electronically as *T. castaneum.* There was a reasonably good degree of correlation between electronic counts of IRSI 28–59 and manual

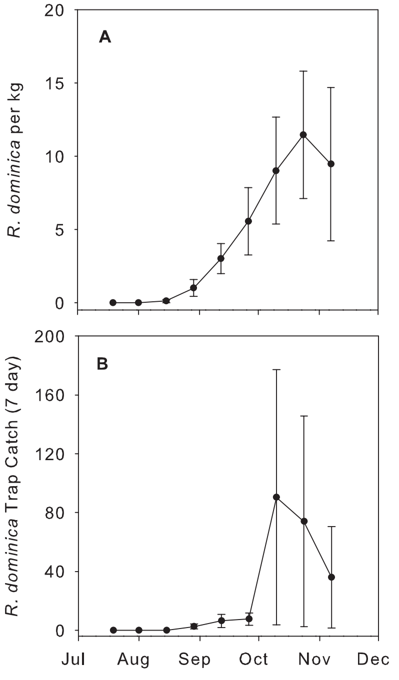

Fig. 5. 2006 Seasonal changes in average *R. dominica* density (A) and manual tip counts of *R. dominica* caught in the Insector trap (B). Grain temperature is the same as in Fig. 4.

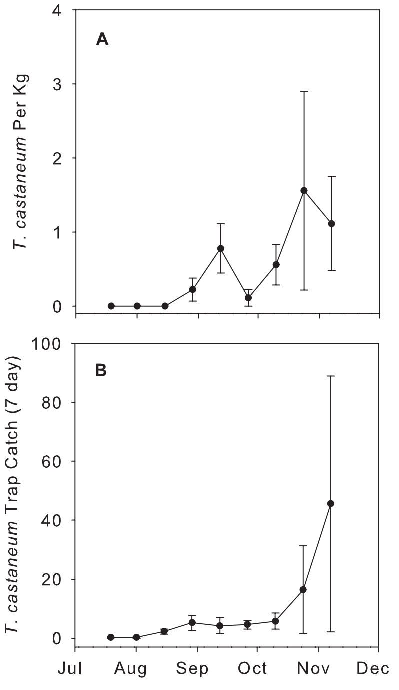

Fig. 6. 2006 Seasonal changes in average *T. castaneum* density (A) and manual tip counts of *T. castaneum* caught in the Insector trap (B). Grain temperature is the same as in Fig. 4.

tip counts of *T. castaneum* in 2005 ($R^2 = 0.67, P < 0.001, N = 95$). The slope was 0.825 ± 0.59, indicating that the electronic counts were only slightly lower than the actual tip counts. In 2006, there were high numbers of *R. dominica,* but low numbers of *T. castaneum.* Thus, we looked at the correlation between IRSI 28–59 counts and manual tip counts of *R. dominica* in this year because most of the insects in this size range would be *R. dominica.* The IRSI 28–59 counts and manual tip counts of *R. dominica* were highly correlated in 2006 ($R^2 = 0.91, P < 0.001, N = 84$). The slope was 0.842 ± 0.029, so the electronic counts were slightly lower than manual tip counts.

Interpretation of Insector trap Catch. Insector records the relative size of an object falling into the trap, a timestamp, and the current grain temperature. For the end user, this is difficult to interpret because both grain temperature and insect species affect the number of insects that are caught by a trap. It is much easier for grain managers to make management decisions based on the insect density (insects per kilogram of grain) than insect trap catch (insects caught per day). We adapted a version of SGA Pro (Flinn et al. 2007) to automatically access the StorMaxPro database and to convert the Insector pulse-size and timestamp data into insect density for *C. ferrugineus, R. Dominica,* and *T. castaneum.* At first we tried using the model from Hagstrum et al. (1998) or Toews et al. (2005) to convert electronic counts of *C. ferrugineus* into insect density. The Hagstrum model underestimated *C. ferrugineus* density in both 2005 and 2006 by ≈4 times, and the Toews et al. (2005) model overestimated *C. ferrugineus* density in both 2005 and 2006 by ≈4–6 times. We developed a new model to predict *C. ferrugineus* density from Insector trap catch and grain temperature based on our data from 2006 (Table 1). We tried several data transformations; residual analysis indicated that a linear model was best. The new model explained 40% of the variation in insect density ($R^2 = 0.40, P = 0.001, N = 90$). For *R. dominica,* we first tried the Hagstrum et al. (1998) model, but this model underestimated *R. dominica* insect density in the grain by ≈4–6 times. The Toews et al. (2005) model for *R. dominica* fit very well; in most cases estimates of *R. dominica* density based on Insector catch were very

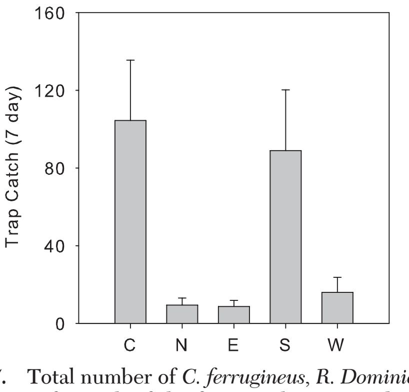

Fig. 7. Total number of *C. ferrugineus, R. Dominica,* and *T. castaneum* for each of the five trap locations (data were combined over 2005 and 2006 and for both grain bins). C, center; N, north; E, east; S, south; and W, west.

Table 1. Regressions equations for grain trier insect density (insects/kg wheat) as a function of manual tip counts of Insector trap catch (average per day) and grain temperature

Species	df	B_0	B_1	B_2	P	Adj. R^2
2005						
T. castaneum	120	0.184 ± 0.075	0.115 ± 0.013		0.001	0.40
2006						
C. ferrugineus	90	2.059 ± 0.690	0.119 ± 0.016	−0.067 ± 0.024	0.001	0.40
R. dominica	90	15.05 ± 2.973	0.654 ± 0.042	−0.438 ± 0.105	0.001	0.75

B_0, B_1, *and* B_2 are the intercept, and coefficients for probe trap catch per day and grain temperature, respectively. Regression equations are not shown for *C. ferrugineus* and *R. dominica* in 2005 and *T. castaneum* in 2006 because of either poor R^2 values or low insect densities.

close to the grain trier insect density. We developed a new model to predict *R. dominica* density from Insector trap catch and grain temperature based on our 2006 data (Table 1). The new model fit the data very well ($R^2 = 0.75$, $P = 0.001$, $N = 90$). No models could be found in the literature to predict *T. castaneum* density based on trap catch and grain temperature in wheat; therefore, we developed a new model based on our 2005 data (Table 1). As mentioned, the 2005 data were used to develop the model for *T. castaneum* because in 2006 the insect densities were too low to fit an accurate model. The new model explained 40% of the variation in insect density ($R^2 = 0.40$, $P = 0.001$, $N = 120$).

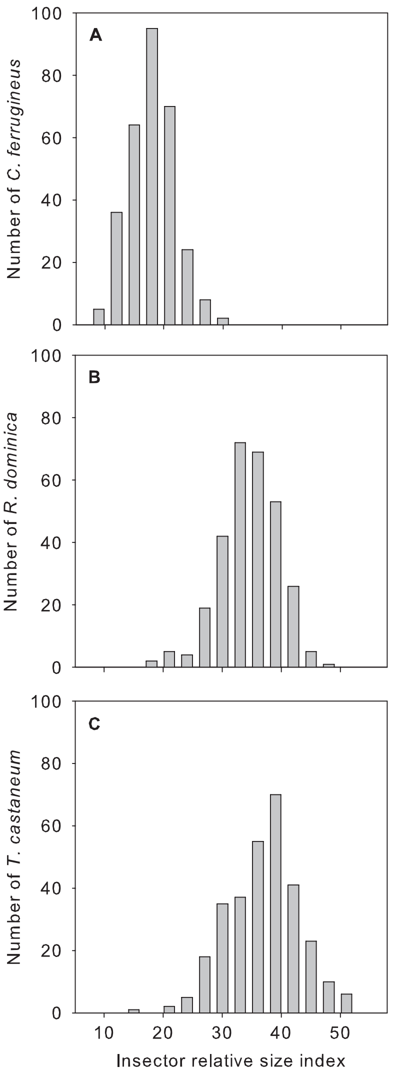

Fig. 8. Frequency distributions of IRSI for 300 adults each of *C. ferrugineus* (A), *R. dominica* (B), and *T. castaneum* (C). The adults were obtained from the grain bins used in this study. Dead adults were dropped through a calibrated Insector under laboratory conditions.

Comparison of Treatment Recommendations. We compared treatment recommendations using either grain trier estimates of insect density or interpreted insect density based on Insector trap catch (Table 2). In this comparison, we assumed that the grain trier estimates of insect density reflect the actual insect density in the grain. A threshold of more than two

Table 2. Comparison of management decisions made by Stored Grain Advisor Pro in 2005 by using grain trier and electronic Insector trap catch data

	Date	Grain trier[a]	Insector[b]	Fumigate trier	Fumigate Insector
Bin 21	30 Aug. 2005	0.00			
	13 Sept. 2005	1.21	1.65	No	No
	27 Sept. 2005	3.42	4.04	Yes	Yes
	11 Oct. 2005	0.88			
	25 Oct. 2005	**1.21**	**6.11**	**No**	**Yes**
	8 Nov. 2005	1.43	1.13	No	No
	22 Nov. 2005	1.32	1.37	No	No
	7 Dec. 2005	**2.98**	**0.86**	**Yes**	**No**
	21 Dec. 2005	**2.87**	**0.30**	**Tes**	**No**
	4 Jan. 2006	**3.64**	**0.97**	**Yes**	**No**
	18 Jan. 2006	**4.30**	**1.01**	**Yes**	**No**
Bin 22	30 Aug. 2005	0.11			
	13 Sept. 2005	1.21	0.86	No	No
	27 Sept. 2005	**0.66**	**4.30**	**No**	**Yes**
	11 Oct. 2005	1.43			
	25 Oct. 2005	**1.21**	**5.50**	**No**	**Yes**
	8 Nov. 2005	**2.43**	**1.48**	**Yes**	**No**
	22 Nov. 2005	1.43	1.85	No	No
	7 Dec. 2005	1.32	1.52	No	No
	21 Dec. 2005	0.66	0.51	No	No
	4 Jan. 2006	1.71	1.21	No	No
	18 Jan. 2006	1.91	1.66	No	No

Fumigation decision is based on a threshold of two or more *C. ferrugineus* per kg of wheat (bold text indicates treatment decision disagreement).

[a] *C. ferrugineus* per kilogram of wheat.

[b] Converted Insector electronic trap catch per day into *C. ferrugineus* per kg of wheat by using regression equation from 2006 (Table 1).

Table 3. Comparison of management decisions made by Stored Grain Advisor Pro in 2005 by using grain trier and electronic Insector trap catch data

	Date	Grain trier[a]	Insector[b]	Fumigate trier	Fumigate Insector
Bin 21	30 Aug. 2005	0.00			
	13 Sept. 2005	0.22	1.59	No	No
	27 Sept. 2005	**1.43**	**2.30**	**No**	**Yes**
	11 Oct. 2005	1.21			
	25 Oct. 2005	**1.66**	**2.52**	**No**	**Yes**
	8 Nov. 2005	1.99	1.23	No	No
	22 Nov. 2005	1.55	1.08	No	No
	7 Dec. 2005	0.22	0.46	No	No
	21 Dec. 2005	0.88	0.15	No	No
	4 Jan. 2006	0.11	0.18	No	No
	18 Jan. 2006	0.00	0.30	No	No
Bin 22	30 Aug. 2005	0.00			
	13 Sept. 2005	0.11	1.00	No	No
	27 Sept. 2005	**0.55**	**2.27**	**No**	**Yes**
	11 Oct. 2005	0.77			
	25 Oct. 2005	0.33	1.36	No	No
	8 Nov. 2005	0.33	0.51	No	No
	22 Nov. 2005	0.11	0.48	No	No
	7 Dec. 2005	0.33	0.48	No	No
	21 Dec. 2005	0.00	0.10	No	No
	4 Jan. 2006	0.00	0.27	No	No
	18 Jan. 2006	0.00	0.13	No	No

Fumigation decision is based on a threshold of two or more *T. castaneum* per kg of wheat (bold text indicates treatment decision disagreement).

[a] *T. castaneum* per kilogram of wheat.

[b] Converted Insector trap catch per day into *T. castaneum* per kg of wheat by using regression equation from 2006 (Table 1). Data that are missing for Insector were caused by problems with the system hardware.

insects per kg of wheat is considered a level that requires fumigation. In 2005 for bin 21, SGA Pro correctly predicted that treatment was necessary on 27 September. However, in December and January, SGA Pro underestimated insect density in the grain and did not recommend treatment. It may be that at cold grain temperatures (<15°C) insect traps do not work well to predict insect density because very few of the insects may be moving in the grain. For bin 22, SGA Pro recommended treatment of the grain almost 1 mo earlier than grain trier samples did. The reasons for this are unclear, but it may be due to the high psocid populations in the grain. Psocids falling in proximity could be detected as *C. ferrugineus* (Arbogast et al. 2000), thereby leading to spuriously large counts.

We compared treatment recommendations for *T. castaneum* in 2005 (Table 3). SGA Pro's estimates of insect density based on trap catch were fairly close to the grain trier estimates on most dates. None of the grain trier estimates for insect density exceeded two insects per kg in either grain bin. SGA Pro estimated insect densities >2 insects per kg on a few dates. We do not see this as a problem because the grain trier estimates were only slightly <2 insects per kg on these dates. In 2006, the estimates made by SGA Pro for *C. ferrugineus* were similar to the grain trier estimates of insect density (Table 4). However, as in 2005, the model tended to slightly overestimate *C. ferrugineus* density on a few occasions.

Table 4. Comparison of management decisions made by Stored Grain Advisor Pro in 2006 by using grain trier and electronic Insector trap catch data

	Date	Grain trier[a]	Insector[b]	Fumigate trier	Fumigate Insector
Bin 21	19 July 2006	0.0	0.1	No	no
	1 Aug. 2006	0.0	0.0	No	No
	15 Aug. 2006	0.0	0.0	No	No
	29 Aug. 2006	0.2	0.4	No	No
	12 Sept. 2006	0.5	0.6	No	No
	26 Sept. 2006	**1.5**	**2.7**	**No**	**Yes**
	10 Oct. 2006	**1.5**	**2.2**	**No**	**Yes**
	24 Oct. 2006	1.3	1.6	No	No
	7 Nov. 2006	**1.5**	**2.7**	**No**	**Yes**
Bin 22	19 July 2006	0.0	0.0	No	No
	1 Aug. 2006	0.0	0.1	No	No
	15 Aug. 2006	0.0	0.0	No	No
	29 Aug. 2006	0.5	0.4	No	No
	12 Sept. 2006	0.8	0.5	No	No
	26 Sept. 2006	1.2	1.9	No	No
	10 Oct. 2006	**1.2**	**2.6**	**No**	**Yes**
	24 Oct. 2006	1.0	1.5	No	No
	7 Nov. 2006	2.1	2.1	Yes	Yes

Fumigation decision is based on a threshold of two or more *C. ferrugineus* per kg of wheat (bold text indicates treatment decision disagreement).

[a] *C. ferrugineus* per kilogram wheat.

[b] Converted Insector trap catch per day into *C. ferrugineus* per kg of wheat by using regression equation from 2006 (Table 1).

We compared treatment recommendations for *R. dominica* in 2006 by using grain trier estimates and interpreted Insector counts (Table 5). SGA Pro incorrectly recommended treatment on 19 July for bin 21. This may have been due to hardware problems with two of the Insectors in that bin. Other than this one anomaly, SGA Pro recommended treatment very

Table 5. Comparison of management decisions made by Stored Grain Advisor Pro in 2006 by using grain trier and electronic Insector trap catch data

	Date	Grain trier[a]	Insector[b]	Fumigate trier	Fumigate Insector
Bin 21	**19 July 2006**	**0.0**	**2.14**	**No**	**Yes**
	1 Aug. 2006	0.0	0.64	No	No
	15 Aug. 2006	0.1	0.49	No	No
	29 Aug. 2006	**1.0**	**2.48**	**No**	**Yes**
	12 Sept. 2006	**3.0**	4.85	**Yes**	Yes
	26 Sept. 2006	5.6	5.92	Yes	Yes
	10 Oct. 2006	9.0	10.54	Yes	Yes
	24 Oct. 2006	11.5	6.57	Yes	Yes
	7 Nov. 2006	9.5	8.33	Yes	Yes
Bin 22	19 July 2006	0.0	1.69	No	No
	1 Aug. 2006	0.0	1.16	No	No
	15 Aug. 2006	0.3	0.96	No	No
	29 Aug. 2006	**0.7**	**3.33**	**No**	**Yes**
	12 Sept. 2006	2.2	3.99	Yes	Yes
	26 Sept. 2006	5.8	7.69	Yes	Yes
	10 Oct. 2006	18.3	19.02	Yes	Yes
	24 Oct. 2006	11.8	6.98	Yes	Yes
	7 Nov. 2006	10.8	5.60	Yes	Yes

Fumigation decision is based on a threshold of two or more *R. dominica* per kg of wheat (bold text indicates treatment decision disagreement).

[a] *R. dominica* per kg of wheat.

[b] Converted Insector trap catch per day into *R. dominica* per kg of wheat by using regression equation from 2006 (Table 1).

accurately during the storage duration for both bins. In both bins 21 and 22, SGA Pro tended to recommend treatment 2 wk earlier than grain trier sampling. However, the SGA Pro density estimates were very close to the grain trier estimates in most cases.

Discussion

The regression models we developed for predicting insect density from Insector trap catch and grain temperature explained from 40 to 75% of the variation in insect density. However, because the models were developed from these data, they can only be fully validated by testing them on other data. Ideally, these future tests would be done in actual grain bins and not under laboratory conditions. The model by Hagstrum et al. (1998) underestimated *C. ferrugineus* and *R. dominica* density. One reason for this may be the physical differences between the two traps. The WBII trap used by Hagstrum does not have upward sloping holes like the Insector trap; this may allow it to catch more insects compared with the Insector trap (given similar grain conditions and trapping duration). Hagstrum's model underestimated insect density more for *R. dominica* than for *C. ferrugineus.* There may be behavioral differences between these two species that influence Insector trap catch. For example, *R. dominica* may be more reluctant to walk up the inclined hole to enter the Insector trap than *C. ferrugineus.* Because the WBII trap does not have upward sloping holes, *R. dominica* trap catch could be greater than Insector trap catch under similar conditions. Nevertheless, the use of upward sloping holes in Insector is a good feature because it reduces the chance of small grain particles and dockage falling into the trap and being erroneously counted as insects.

The regression equations for *C. ferrugineus* and *R. dominica* had a negative coefficient for temperature, indicating that trap catch increased with decreasing grain temperature. In the fall, the traps in the south (S) and center (C) position caught a lot more insects, probably because the grain was warmer there, but also because insects may have been moving from cooler regions to warmer regions of the grain bin. Previous research has shown that *C. ferrugineus* will move from cooler to warmer areas of the grain (Flinn and Hagstrum 1998). Thus, even though the grain was slowly cooling, trap catch may have been increasing in certain locations because of increased migration from cool to warm areas of the grain mass.

The biggest problem facing the optimal use of the Insector system is its inability to tell the difference between *R. dominica* and *T. castaneum* because of their similarity in size. In some locations this may not be a problem because *R. dominica* is rarely present (northern United States and Canada) (Fields et al. 1993). When both species are suspected, one solution may be to determine what the proportion of each species in the grain is by using the solid Insector tips for 1 wk and then pulling the traps to see what was caught. In the future, perhaps new sensors can be used that are able to detect differences in color. This may allow better species identification.

We did have problems with the Insectors at certain times during the study because of high psocid populations in the bin. The high psocid counts tended to overload the memory chip on the Insector, and they were unable to unload the data they had collected to the PC. Thus, the electronic counts sometimes underestimated the actual number of insects that fell into the Insector tip. OPI has since developed new software and hardware that solves this problem by allowing the user to filter out counts of objects that are in the psocid size range.

The combination of SGA Pro with the OPI Insector system should prove to be a useful tool for automatic monitoring of insect pests in stored grain. Currently, SGA Pro runs separately from the StorMaxPro software. The best solution would be to combine the two programs so that the data are automatically interpreted for the user within one software program.

Acknowledgments

We thank Ken Friesen (USDA–ARS, Manhattan, KS) for amazing technical expertise and enthusiasm during this project. We thank David Crompton, Ron Larson, and Fuji Jian (OPI Systems, Inc.) for the StorMaxPro system and for providing technical expertise. We also thank Paul Fields (Agri-Food and Agriculture Canada) for reviewing an earlier version of this manuscript.

References Cited

Arbogast, R. T., P. E. Kendra, D. K. Weaver, and D. Shuman. 2000. Insect infestation of stored oats in Florida and field evaluation of a device for counting insects electronically. J. Econ. Entomol. 93: 1035–1044.

Burkholder, W. E. 1984. Stored-product insect behavior and pheromone studies: keys to successful monitoring and trapping, pp. 20–33. *In* Proceedings of the 3rd International Working Conference on Stored-Product Entomology, 23–28 October 1983, Manhattan, KS. Kansas State University, Manhattan, KS.

Fargo, W. S., D. Epperly, G. W. Cuperus, B. C. Clary, and R. Noyes. 1989. Effects of temperature and duration of trapping on four stored grain insect species. J. Econ. Entomol. 82: 970–973.

Fields, P. G., J. Van Loon, M. G. Dolinski, J. L. Harris, and W. E. Burkholder. 1993. The distribution of *Rhyzopertha dominica* (F.) in western Canada. Can. Entomol. 125: 317–328.

Flinn, P. W., and D. W. Hagstrum. 1998. Distribution of *Cryptolestes ferrugineus* (Coleoptera: Cucujidae) in response to temperature gradients in stored wheat. J. Stored Prod. Res. 34: 107–112.

Flinn, P. W., D. W. Hagstrum, C. Reed, and T. W. Phillips. 2007. Stored grain advisor pro: decision support system for insect management in commercial grain elevators. J. Stored Prod. Res. 43: 375–383.

Hagstrum, D. W., P. W. Flinn, and Bh. Subramanyam. 1998. Predicting insect density from probe trap catch in farm-stored wheat. J. Stored Prod. Res. 34: 251–262.

Lippert, G. E., and D. W. Hagstrum. 1987. Detection or estimation of insect populations in bulk-stored wheat with probe traps. J. Econ. Entomol. 80: 601–604.

Loschiavo, S. R., and J. M. Atkinson. 1967. A trap for the detection and recovery of insects in stored grain. Can. Entomol. 99: 1160–1163.

Loschiavo, S. R., and L. B. Smith. 1986. Population fluctuations of the rusty grain beetle, *Cryptolestes ferrugineus* (Coleoptera: Cucujidae), monitored with insect traps in wheat stored in a steel granary. Can. Entomol. 118: 641–647.

Madrid, F. J., N.D.G. White, and S. R. Loschiavo. 1990. Insects in stored cereals, and their association with farming practices in southern Manitoba. Can. Entomol. 122: 515–523.

Shuman, D., J. A. Coffelt, and D. K. Weaver. 1996. A computer-based electronic fall-through probe insect counter for monitoring infestation in stored products. Trans. Am. Assoc. Agric. Eng. 39: 1773–1780.

Shuman, D., D. K. Weaver, and R. G. Larson. 2005. Performance of an analytical, dual infrared-beam, stored-product insect monitoring system. J. Econ. Entomol. 98: 1723–1732.

Systat Software, Inc. 2007. Statistics II, version 12. Systat Software, Inc., San Jose, CA.

Toews, M. D., T. W. Phillips, and M. E. Payton. 2005. Estimating populations of grain beetles using probe traps in wheat-filled concrete silos. Environ. Entomol. 34: 712–718.

Vela-Coffier, E. L., W. S. Fargo, E. L. Bonjour, G. W. Cuperus, and W. D. Warde. 1997. Immigration of insects into on-farm stored wheat and relationships among trapping methods. J. Stored Prod. Res. 33: 157–166.

Wakefield, M. E., and P. M. Cogan. 1999. The use of a managed bulk of grain for the evaluation of PC, pitfall beaker, insect probe and WBII probe traps for monitoring *Sitophilus granarius* during the winter and summer in the UK. J. Stored Prod. Res. 35: 329–338.

White, N.D.G., and S. R. Loschiavo. 1986. Effects of insect density, trap depth, and attractants on the capture of *Tribolium castaneum* (Coleoptera: Tenebrionidae) and *Cryptolestes ferrugineus* (Coleoptera: Cucujidae) in stored wheat. J. Econ. Entomol. 79: 1111–1117.

Received 29 October 2008; accepted 1 April 2009.